Event-related potentials and information processing

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SUMMARY

In 1978 we replicated an experiment designed by Squires *et al.* (1977). It was an auditory odd-ball experiment, especially chosen for its' simplicity. The first ERPs in Groningen were measured at this time. The results were very similar to those reported by Squires, which encouraged us to continue measuring EEG in the next experiment. The latter was a replication of one of the experiments reported by Schneider & Shiffrin (1977), carried out as a partial fulfillment of the requirements for a doctoral degree (Brookhuis, Don, Mulder, & Mulder, 1980). In a varied mapping situation, a late positive component appeared to peak sharply around 500 msec in the easiest condition (memory load 1 and display load 1). Conditions that were more difficult to the subject (memory load 2 or 4 in combination with display load 4) evoked less sharp peaks, between 600 and 800 msec, the latencies and amplitudes being dependent upon load and response type (see Brookhuis *et al.*, 1980).

The successful accomplishment of these experiments smoothed the way for a grant from the Netherlands Organisation for the Advancement of Pure Research (Z.W.O.). For this, we conceived a series of experiments within the general framework for theories of information processing, proposed by Shiffrin & Schneider (1977). The concomitant measurement of EEG for the derivation of ERPs looked very promising at that time, since Donchin (e.g., Donchin, 1979) and others demonstrated and advocated the usefulness of ERPs in information processing research. If the late positive component of the ERP, called P300 by most researchers, was indeed an index of stimulus evaluation time, as Donchin suggested, information processing research could be greatly enhanced and theories could possibly be falsified, supported or extended.

We set out to test the hypotheses generated by Shiffrin & Schneider's model of information processing with our new tool, the ERP. In chronological order the hypotheses to be tested were

- 1 memory load has an influence on the memory comparison process, indicated by stimulus evaluation time (P300 latency), and therefore on reaction time, but not on earlier parts in the flow of information processing
- 2 display load has an influence on the time needed for stimulus identification, and therefore on stimulus evaluation time, and on reaction time
- 3 targets take less time to identify than when there is no target, thus stimulus evaluation time is shorter for positive trials than for negative trails

- 4 the differential effect, put forward in the last hypothesis, increases with increasing processing load
- 5 response probability has an effect on response determination, preparation and execution processes, but not on stimulus evaluation processes
- 6 stimulus similarity influences early (sub)processes in the flow of information processing
- 7 stimulus-response compatibility only affects response determination and has no influence on stimulus evaluation
- 8 response speed instructions have an exclusive influence on response preparation and execution processes
- 9 learning or practice has a general, speed enhancing effect on all (sub)processes
- 10 mapping of stimuli, consistent (i.e. memory set items are consistently the same throughout a vast number of trials) versus varied (i.e. memory set items are chosen randomly in each trial from the whole set of imperative stimuli), decreases the time needed for all (sub)processes, but will in the long run, when automaticity emerges, cause the stimulus comparison process to be bypassed
- 11 stimulus degradation will influence the flow of information processing from the beginning and have an effect on the first (sub)processes untill stimulus evaluation is completed.

Six experiments were carried out to test these hypotheses and explore and develop a number of new techniques with respect to data collection, signal processing and result presentation.

In the first experiment, hypotheses 1, 2, 3 and 4 were tested. Processing load was varied by varying memory load (1, 2 or 4 items to be held in memory) and display load (1, 2 or 4 items on the display to be searched for a memory item), combined to result in 1, 4, 8 or 16 possible comparisons. On half of the trials the display set contained an item of the memory set. The reaction time data showed signs of a self-terminating search process when the number of comparisons to be made was more than 4. The data showed a good fit with predictions from Shiffrin & Schneider's model of information processing ($R = .77$). The late postive component indeed appeared to be sensitive to the number of comparisons. However, although latencies for negative responses were longer than latencies for positive responses, they did not show a significant interaction. Contrary to the reaction time data, the P300 latency data suggested an exhaustive search process. A possible explanation for this phenomenon might be that stimulus evaluation progresses until the complete display is processed, while the response can be emitted on the basis of sufficient evidence somewhere in between, only in the case of a positive response. Stimulus evaluation and response organization appeared to be rather independent.

In the second experiment, response probability was varied (hypothesis 5). The ratio between positive and negative responses could be either 50:50 or 25:75. The subjects were explicitly trained in these conditions and instructed to prepare for the most probable, negative response in the 25:75 condition. In addition to this manipulation, we also varied processing load again, i.e. memory set size 1 or 2 combined with display set size 4. The results of the first experiment were replicated with respect to the interaction of set size and response type in the reaction time data, which was again absent in the latency data of the late positive component. The latter was renamed "P3b", to distinguish it from the fixed component around 300 msec, named the "P3a", together establishing the P3 complex. Response probability affected the response speed, but contrary to the hypothesis, had a similar effect on P3b latency as well. Moreover, not all subjects showed the required presetting effect in their reaction times, whereas the P3b latencies consistently showed the response probability effect across all subjects. The failure of this subgroup of subjects to preset the motor system was apparent in the absence of a CNV before the presentation of the imperative stimulus, which was in turn clearly present in the ERPs of the subjects who performed well according to the instructions.

The third experiment concerned a binary classification task in which signal similarity and S-R compatibility were additively varied (hypothesis 6 and 7). The design of this experiment makes it fall outside the scope of this thesis, but the results are published extensively elsewhere (Mulder *et al.*, 1984).

The fourth experiment actually was a pilot experiment. Six subjects were trained to emit responses either as fast as they could, at the expense of making errors but without actually guessing, or as accurately as possible (hypothesis 8). Memory set and display set configuration were similar to the configuration in the second experiment. The data showed that speed instructions had a substantial decreasing effect on reaction times, although the interaction between response type and processing load persisted. The latency of the P3b component seemed to be longer in the speed condition, but the low number of subjects prevented us from finding a significant effect. Therefore, after the period of the ZWO grant had expired, we replicated this particular experiment with ten more subjects. The results now confirmed that the latency of the P3b component was increased significantly by some 50 msec, when speed was emphasized. Directing attention to the motor processes apparently slowed down the stimulus evaluation. A considerable CNV was visible before the presentation of the imperative stimulus. In the accuracy condition, P3b was earlier than in the speed condition but had a lower amplitude. The latter phenomenon was probably due to a processing negativity that coincided with the P3 complex. No CNV was found in the accuracy condition. The relative independence of stimulus evaluation and response organization was again demonstrated.

In the fifth experiment processing load was varied by varying display set size, which could be either 1 or 3, in a 50:50 ratio. Memory set size was always 3. Additionally, (2x)6000 trials of training, or practice, had to be endured by the subjects in each of two situations, varied mapping and consistent mapping (hypotheses 9 and 10). Training had a substantial effect in decreasing the reaction times and a small effect in decreasing the latencies of early and late components in the ERP. The relative independence of stimulus evaluation and motor processes is illustrated nicely, especially in the consisted mapping condition. After 6000 trials of practice, responses are emitted very fast, even before the occurrence of the P3b component, almost without any errors. However, hypothesis 8 was not confirmed. On the contrary, P3b components showed the highest amplitudes ever, after training in the consisted mapping condition. The reason for this is probably that in the long run the overlapping processing negativity disappears. Moreover, the effect of processing load and the interaction of response type and processing load did not disappear. No "flat functions", as predicted by the theory of Shiffrin & Schneider (1977), occurred.

The sixth experiment aimed at manipulating the early processes in the flow of information processing by degrading the stimulus (hypothesis 11). Again processing load was varied additively by varying display set size (1 or 2), combined with a fixed memory set size (4). Degradation was accomplished by presenting incomplete letters for imperative stimuli to the subject. The results only partly replicated earlier results with respect to the interaction of response type and processing load. The partial failure was caused by the main manipulation, degradation, that had such large effects on reaction times that at the highest processing load, especially negative responses met a ceiling effect. Also, the P3b component was hard to detect in the ongoing ERP, notwithstanding a sophisticated peak detection technique. Nevertheless, effects were according hypothesis 11, except for the above mentioned disturbance, i.e. stimulus degradation affected the (sub)processes in the flow of information processing right from the start.

The experiments were devised to test hypotheses that were originally based on performance data alone, i.e. reaction time and errors. Although the overt behaviour was undoubtebly a rich source of information, ERPs constituted an invaluable supplement to that. Some of the conclusions of Shiffrin & Schneider, that are consequences of the model, appeared to be intenable.

ERP data can also be a valuable complement to parameters from the overt behaviour. For instance, areas such as individual differences can profit considerably from psychophysiology (cf., Mulder, Wijers, Smid, Brookhuis, & Mulder, 1989). Early components (e.g., N2) and late component (e.g., P3b) are demonstrated to be useful indicators of involvement and duration of (sub)processes in the flow of information processing; slow phenomena such as CNV and processing negativity are indicators of strategy, at the individual level. The results of the reported experiments have at least helped to clarify the significance of these new tools in the field of information processing research.